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13. ABSTRACT *(Maximum 200 words)*

In this research, the synthesis reactions of Ni and Al powder mixtures at the shock front in exothermic mixtures were studied. An existing, but non-functioning, two-inch diameter gas gun was modified into a powder gun to accommodate higher velocities of impact and larger specimen size requirements. Effects of impact velocity and particle size of the constituents on reaction kinetics were determined. The unique experimental data is currently being used to guide the development of models aimed at describing the shock wave interaction with exothermic mixtures with the goal of a better understanding of the formation of intermetallic compounds.

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SHOCK WAVE INTERACTIONS WITH EXOTHERMIC MIXTURES

FINAL PROGRESS REPORT

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U.S. ARMY RESEARCH OFFICE

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STATEMENT OF PROBLEM

Since the late 1960's, faculty and students at North Carolina State University have been investigating the response of materials to high deformation rates. A high rate of material deformation is normally obtained by impacting a sample of material with a high velocity projectile. This process is known as shock loading since the impact creates shock waves within the material. The equipment used in these investigations usually includes a smoothbore barrel to guide cylindrical projectiles; a test chamber, which houses the target specimen at the end of the barrel; and some type of catching device to stop the debris resulting from impact. The entire system is known as an accelerator. To meet various research objectives, a number of different accelerator systems have been designed and fabricated at the University. Most of these accelerators, however, have been dismantled.

In this research, the synthesis reactions of Ni and Al powder mixtures at the shock front in exothermic mixtures were studied. An existing, but non-functioning, two-inch diameter gas gun was modified into a powder gun to accommodate higher velocities of impact and larger specimen size requirements. Effects of impact velocity and particle size of the constituents on reaction kinetics were determined. The unique experimental data is currently being used to guide the development of models aimed at describing the shock wave interaction with exothermic mixtures with the goal of a better understanding of the formation of intermetallic compounds.

SUMMARY OF RESULTS

The summary of results will be divided into three major tasks, each of which is fully described in individual theses, as cited below. The first task involved modifying the existing 2 inch diameter gas gun, relocating it to remote off-campus laboratory, designing a new catcher chamber, developing operational procedures, and finally, calibration studies. The second task focused on studying when exothermic chemical reactions occur in Ni/Al powder mixtures. A major finding is that the chemical reaction is initiated not by a pressure threshold level, but by a pressure *jump* threshold level. This new finding contradicts the energy threshold theory and the melting model theory. Finally, the third task involved modifying the breech assembly so that

pressurized gas could be used to accelerate projectiles. This task was undertaken with the goal of allowing much quicker turn around between shots as set-up and cleanup is easier when using gas as opposed to gun powder. In addition, an optical method for measuring the projectile velocity at the muzzle was developed as part of this task. This non-intrusive method eliminates the need for mechanical velocity pins which fail on occasion and thus render shots when they fail useless. Finally, experience with the use of polyvinylidene fluoride (PVDF) strain gages gained in this last task.

Design and Calibration of the NCSU 2" Powder Gun

A powder accelerator system capable of firing two inch diameter projectiles at high velocities was designed and fabricated at North Carolina State University. The accelerator, which uses gunpowder as the propellant, was used in an investigation of material response to shock loading as described below. The major components of the accelerator include a twenty foot long barrel a breech mechanism, a target chamber, and a catching device to stop the debris of impact. The system was designed to fire a maximum powder charge of 850 grams and a maximum projectile weight of 3 pounds. A number of trial firings were made to test system operation and to collect projectile velocity data as part of this first task. The deviation of experimentally measured velocity from theoretically predicted velocity was examined so as to ascertain calibration factors to improve future predictions of projectile velocity. During this first task, the accelerator delivered projectile velocities ranging from 744 to 1534 m/s. The velocity of 1534 m/s was obtained when firing a 245 gram projectile with 425 grams of powder, which was the largest powder charge used in the trial firings. A 490 gram projectile fired with 425 grams of powder acquired the greatest kinetic energy, the value being 448.7 kJ. The use of powder charges greater than 425 grams, however, cannot be tested until better shock absorbers, which dampen the recoil of the catching device, are installed. For powder charges less than 425 grams, the trial firings have shown the accelerator to be ready for its intended use.

Shock Wave Induced Exothermic Reactions in Ni-Al Powder Mixtures

Experimental tests were used to study the exothermic chemical reaction induced by the shock wave in the Ni-Al powder mixture system. The purpose of this investigation was to study the effects of shock wave intensity, particle size, and loading conditions of the shock wave on the exothermic chemical reaction. The shock wave was generated by the planar impact of a projectile on target containing a powder mixture using the NCSU 2" gun as described above. A manganin gauge is placed at the back of the powder sample to measure the pressure-time history. The difference between the measured pressure and the pressure values predicted by inert Hugoniot calculations indicted that chemical reactions occurred at the shock front on the time scale of a microsecond or even shorter. Copper projectile to copper target impact tests were conducted to calibrate the pressure measurement system. These pressure measurements agreed well with the theoretically predicted values. Tests were also conducted to validate the previous time-resolved pressure measurements in Ni-Al powder mixtures conducted using the NCSU 19 mm gun. Close agreement with the previous chemical reaction threshold values have been obtained using the 2" gun. The currently designed target structure, allowed for consistent and stable pressure profiles in these experiments, and thus provided the possibility for studying of the reaction kinetics. Also, the effect of particle size on the reaction threshold was studied by conducting the tests with larger particle sizes than used in the previous tests. The results showed that the reaction threshold increases in proportional to the Ni-Al particle size. By adding a thin layer of Al between the Ni-Al powder mixture and the backing plate, the effect of the loading condition on the reaction was studied. Experimental results from two shots confirmed that the reaction is initiated by the reflected wave at the back surface of the powder mixture. These data also showed that the pressure difference between the incident and reflected wave is critical criteria for reaction initiation. The pressure threshold condition for initiation of chemical reaction is in the range of 13.5-14.5GPa. It was also concluded that the energy initiation concept and melting model are not be able to explain the initiation of the reaction. These measurements support the theory that the mechanisms having to do with the mechanical processes inside the mixture at the shock front are responsible for initiation of the chemical reaction. A model for inert powder mixture Hugoniot prediction was used both to analyze the experimentally

constructed Hugoniot curves and to help direct the design of target geometry. Finally, a constitutive model (VIR), where V stands for void; I inert or inactive species; R reactive materials (Horie, 1989), was used to interpret and evaluate the experiment results.

Modifications to the NCSU 2" Accelerator

The 2" accelerator used for shock physics research was modified as part of this third task such that it can use either gunpowder or compressed air to fire a projectile at the target. An air breech assembly, utilizing a wraparound flowplate, and an air system were developed to effect this modification. The air accelerator was designed to operate with compressed air at up to 3000 psi. Additionally, a laser velocimeter was developed to non-intrusively measure projectile velocity at the end of the accelerator's barrel. The air accelerator was fired thirty-eight times to obtain projectile velocity calibration data and also to compare with a theoretical model used to predict projectile velocities. To date, the highest projectile velocity attained using compressed air was 437 m/s at a breech pressure of 2220 psig. Friction, not included in the model, was found to be a significant factor in all shots. The original model was revised, and a second model was developed to empirically account for friction. Ten of these shots were performed to compare the laser velocimeter technique against the more traditional velocity-determination method, the velocity pin technique. The laser velocimeter data closely agreed with those from the velocity pin method up to a projectile velocity of 250 m/s. Above this velocity, the prototype version of the laser velocimeter acted erratically. It is believed that a better, more electrically isolated system, would perform well at maximum projectile velocities. Trial firings of the air accelerator have proven the concepts of the wraparound flowplate and the laser velocimeter. Finally, polyvinylidene fluoride (PVDF) strain gages were evaluated for use in future impact studies at NCSU.

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LIST OF PUBLICATIONS AND TECHNICAL REPORTS

Yang, Y., Gould, R. D., Horie, Y., and Iyer, K. R., "New evidence concerning the shock-induced chemical reaction mechanism in a Ni/Al mixture," in press, 10th Biennial International Conference of the American Physical Society Topical Group on Shock Compression of Condensed Matter, Amherst, MA July 27 - Aug. 1, 1997.

Yang, Y., Gould, R. D., Horie, Y., and Iyer, K. R., "Shock-induced chemical reactions in a Ni/Al powder mixture," in press, *Applied Physics Letters*, **70**, June 23, 1997.

LIST OF INVENTIONS

None

PARTICIPATING SCIENTIFIC PERSONNEL

Three graduate students in the Mechanical and Aerospace Engineering Department at North Carolina State University were supported in part by this research grant. Their names, earned graduate degrees, graduation dates and thesis titles are given below.

1. Hill, James T., MSME, Aug. 1994, "The Design and Calibration of the NCSU 2" Powder Gun"

2. Yang, Yi, PhD, May 1997, "Experimental Study of Shock Wave Induced Exothermic Reactions in Ni-Al Powder Mixtures"

3. Darrell, James H. III, MSME, May 1997, "Modifications to and Testing of the NCSU 2" Accelerator"